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ADJUSTING SELF-INSTRUCTION PROGRAMS TO INDIVIDUAL DIFFERENCES--STUDIES OF CUEING, RESPONDING AND BYPASSING PERIOD INTERIM REPORT.

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AMERICAN INST. FOR RESEARCH IN BEHAVIORAL SCIENCES

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SEVERAL POSSIBLE WAYS OF ADJUSTING SELF-INSTRUCTION PROGRAMS TO INDIVIDUAL DIFFERENCES AMONG LEARNERS WERE EXPLORED IN EXPERIMENTAL PILOT STUDIES. THE PROGRAMS UTILIZED A VARIETY OF RESPONSE MODES AND STEP SIZES, AND PRESENTED TOPICS WITHIN PHYSICS AND MATHEMATICS TO STUDENTS OF 8TH-, 9TH-, AND 10TH-GRADE LEVELS. SCHOLASTIC ABILITY, AS MEASURED BY SCHOOL AND COLLEGE ABILITY TESTS, SERVED AS A CONTROL MEASURE IN THE OPTIONAL RESPONSE AND BYPASSING STUDIES. IDEAS FOR FUTURE RESEARCH WERE PRESENTED. BYPASSING APPEARS TO BE A POTENTIALLY VERSATILE TECHNIQUE FOR ADAPTING PROGRAMED INSTRUCTION TO INDIVIDUAL DIFFERENCES. (LP)

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Interim Report

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Vincent N. Campbell

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Approaching the Problem

The coming of programed instruction, especially "teaching machines", has given the field of training and education an aura of participation in the current general technological revolution. A shadowy side of this aura shows itself in the widespread, if mild, concern over the dehumanization and loss of individuality which might accompany automated instruction. Investigations such as the present one into ways of adjusting self-instruction programs to the needs and capabilities of individual learners seem to fit the times, and may help to minimize these aversive characteristics rightly or wrongly attributed to teaching machines.

There is a rationale for the present kind of research more serious than the avoidance of "mechanistic mass homogenization." I refer to the almost universally accepted goal of educating every person to make the most of his unique assets. This goal is perhaps more often cited in support of variation in subject matters taught, but it applies as appropriately to variation in educational technique. Can a group of students learn most effectively and economically by all using the one procedure proven most effective on the average? Or should different students use different procedures tailored to those individual differences in abilities, personality and past experience which relate most highly to learning efficiency? Either hypothesis is tenable in general; both have served as working assumptions in education.

It is disheartening to anticipate, but not unlikely, that the answer may vary as one applies the question to different student populations, different subject matters, and different classes of instructional methods. This sets probable limits on the generality of the findings of any one study, making the general effort larger and more complicated but no less important. The present project limits itself from the start to self-instruction programs, and the question

becomes, "Can such a program on Topic X be gainfully varied to adjust to individual differences among students?"

Several pioneers in the field of automated instruction (7) have made the point that existing self-instruction programs are in some ways better attuned to individual differences among students than are conventional classroom procedures. Rate of introduction of new learning material, in particular, is said to be geared to the individual in automated instruction. Yet conventional reading shares this same advantage.

Requiring the learner to make frequent relevant responses followed by immediate feedback also seems to cater to the idiosyncratic learning process of the individual, but this may be illusory. In a linear self-instruction program all students receive the same sequence of learning material and response demands. Their responses may differ but so may students listening to the same lecture, or reading the same book, differ in their thoughts and note-taking.

"Branching" or "bypassing," in which students receive different sequences of materials as a function of their learning progress, is one feature of some existing programs which is clearly designed to adjust to individual differences among learners. This technique has been the main focus of research on the present project, largely because it appears to be a potentially practicable means of adapting to a broad spectrum of individual differences. A later section of this report treats in detail the research findings to date regarding bypassing.

Apart from branching, gross age differences seem to be the only kind of individual differences taken into account in automated instruction. Even adjusting to age differences has consisted mostly in accepting, a priori, the reasonable assumption that a program can rely more upon complex abstract language with older children and adults than with younger children.

Since the general problem area of programing for individual differences has little previous research to lend it structure, it seems appropriate to begin by briefly outlining some major issues in research strategy.

Demonstrability vs. Practicality

The question, "Can self-instruction programs be gainfully adapted to student differences?" implies two research objectives corresponding to two definitions of "gainfully."

(1) The first objective is to determine whether program variations increase the overall effectiveness of learning. Restricting "gain" to learning achievement, the research question becomes, "Do student difference interact with program differences in determining success of learning?" In other words, is Program A more effective for some learners and Program B more effective for other learners? (A and B need not be separate programs; they could as well be different sequences of material within a branching program.) As in traditional academic studies of learning, the sole criterion of the worth of program variation here is learning success, usually measured by either level of mastery, time required, or both (time-efficiency of learning).

(2) The second objective is to decide whether the enhancement of learning (if any) is worth the trouble. Practical application of any technique for adapting programs to student differences requires weighing the potential cost and inconvenience of the technique against the improvement in learning that it may achieve. One might demonstrate that using two or more entirely different programs designed for students of different profiles of ability or interest, instead of using one program for everyone, yields a statistically significant increment in learning. But if the gain in learning is slight, multiple programs may not be worth their development and production costs.

These practical factors have been kept in mind in the present project, both in selecting techniques for experimentation and in interpreting the results. However no detailed analyses of costs have been undertaken.

Choice of Variables for Study

A second major issue in research strategy is the choice of variables on which individual differences might relate to effectiveness of self-instruction. These are mainly of two kinds: traditional individual difference variables and learning process variables.

A substantial body of data has been accumulated on traditional dimensions such as intelligence, factored abilities and interests. Most learning process variables, on the other hand, derive from studies seeking general principles of learning, and data on individual differences in these learning processes are less accessible. "Reinforcement," "cueing," and "size of step" are examples of such variables, in which dimensions of individual difference are implied rather than stated. Thus, in the "size-of-step" example different step sizes might be optimal for different learners. Quite often the underlying individual difference dimension remains unlabeled, except perhaps as "ability to learn by Method A" vs. "ability to learn by Method B."

Selecting a traditional individual difference variable for investigation has the advantage that one can make use of existing measures and norms. For example, one could readily select an average group or extreme groups on that variable as experimental samples. But traditional variables are often of questionable or unknown importance to the learning process which takes place in self-instruction. Variables derived directly from learning theory or the instructional situation may more often appear to have conceptual relevance.

Both traditional measures and learning process variables have been treated as promising sources of individual differences in the present project. There is an endless variety of variables of both kinds, many of which appear to merit investigation. Since one project can involve systematic study of only a few of these, we have tried to limit our major research efforts to those variables which show some evidence of permitting gainful adaptation of programs to individual differences. For this reason our overall strategy has been to begin testing any given hypothesis by exploration with individual subjects and/or a group pilot study. Only if these initial results indicated potentially practical adjustment to individual differences was this hypothesis pursued with a larger research effort.

The following sections report chronologically the several lines of exploration that our research has taken to date. For three of

these (directness of cueing, optional responding, and traditional ability variables) initial evidence did not point to an important and practical way of adjusting programing to individual differences, and research in these directions has not been continued beyond pilot studies. Only the bypassing study yielded initial results sufficiently positive to lead us to expand the study into a larger systematic investigation.

Cueing and Prompting

The commonest framework for discussing programing analytically has been the "cue-response-feedback (or reinforcement)" paradigm. This may have channeled programing prematurely into too heavy an emphasis on response elicitation and the immediate stimulus, to the neglect of other factors such as organization of material and maintenance of interest, and to the neglect of such learning criteria as depth of understanding and critical analysis. Nevertheless, we began our search within this accepted framework.

The first pilot study focused on "directness of cueing," or cueing vs. prompting (1), using small-step, constructed-response programs. The hypothesis was that some persons learn better if the required responses are quite directly prompted (e.g., by having the response word appear elsewhere in the same frame), whereas other persons learn better if the cueing of each response is more indirect so that the learner must construct the right response rather than just repeat it.

The optimal directness of cueing for a learner might be related to any number of personal attributes. An ability to grasp ideas, to formulate and relate, seems to be a reasonable underlying dimension of individual differences here. A person having little of this ability might be expected to learn better with direct prompting and "shaping" of his behavior than by his trying to construct difficult and complex answers often beyond his capability. The reverse might be expected of persons having high ability to formulate and relate ideas, on the basis that constant prompting might be boringly easy while success at anticipating difficult answers might motivate the learner.

Method

Two portions of an experimental, high-school-level physics program (5), one on static electricity and the other on optics, were each modified into two alternate forms presenting the same verbal substance but differing in directness of cueing. Appendix A shows sample frames of the alternate forms of the Static Electricity program. Let us

designate the direct and indirect forms respectively as the "Prompt-form" and the "Cue-form."

In constructing the Cue and Prompt forms of each program, we tried to contrast them in directness of cueing without making them differ in other important features, such as the number and nature of response and feedback words. The Cue-Prompt contrast was also limited by the prerequisite that both forms should fall within palatable bounds of difficulty so that the learner would be neither overwhelmed nor engaged in mechanically copying response words. In final form, each program consisted of 30 to 33 frames typed on 5" x 8" cards, one card per frame.

Eight casually selected students (four of each sex) varying in grade level from 8th to 10th served individually as subjects (Ss). Each S turned the program cards at his own pace and worked through three programs on three separate days, always in the presence of an experimenter, who turned feedback cards showing the correct answers for each frame.

On the first day S was given a practice program on mountaineering, on the second day Static Electricity, and on the third day Optics. Half of the Ss were given the Cue form of Static Electricity and the Prompt form of Optics, the other half received the reverse combination (Prompt-Static Electricity; Cue-Optics). Time required to complete each program was recorded.

Immediately after every learning program S took a test on that topic (the same test was given for both Cue and Prompt forms, of course). The 30-plus items in each test were nearly all open-ended questions calling for answers from one word to one sentence in length. After a two-week interval, each S returned and took the same Static Electricity and Optics tests again. We tried to ensure that S did not know the reason for his return until he arrived for the retention tests.

Results

Time spent on the learning programs ranged from 16 to 24 minutes on Static Electricity, from 17 to 29 minutes on Optics. The Cue and Prompt forms required equivalent average learning times (21.7 and 21.4 minutes, respectively), topic disregarded. In comparing the Cue

and Prompt forms, there was no relation between the time difference (Cue minus Prompt) for an S and his test score difference, so time will be omitted in the remaining discussion of results.

Scores on the immediate and two-week retention tests on the Static Electricity and Optics programs were the principal learning criteria. On both tests, scores were converted to percentages of the maximum possible score. Figure 1 depicts the immediate-test results, and compares the Cue and Prompt-form percent scores for each S separately. Figure 2 presents the corresponding findings on the two-week retention test. In both figures all scores have been adjusted to remove topic differences (Optics yielded generally lower percent scores than Static Electricity). The unadjusted scores are tabled in Appendix B, which also includes summary analyses of variance of the percent scores. As shown in the two figures, there were reversals between persons in the relative effectiveness of the Cue and Prompt forms, some learning better with cueing, others with prompting. It is important to note, however, that these individual differences can be attributed either to form (Cue-Prompt) or to topic (Static-Optics). We tried to choose two topics for which underlying learning ability would be quite similar, without permitting direct transfer between topics, so as to minimize these topic-ability differences. For example, optics and static electricity seemed a better choice than, say, optics and grammar, or theoretical optics and applied optics. Nevertheless, the two sources (form and topic) of individual differences are statistically confounded.

One can still ask whether the individual differences shown in Figures 1 and 2 (whatever their source) are large enough to merit further investigation. More specifically, how much higher is the mean test score obtained by taking each person's empirically best program form, than the mean test score on the one form which is best on the average? On the immediate test (Fig. 1) the Cue form yields a slightly higher mean score (83.2) than the Prompt form (79.2). Only S2 and S8 did better on the Prompt form. The mean difference between a person's best score (Cue or Prompt) and his Cue-form score is only

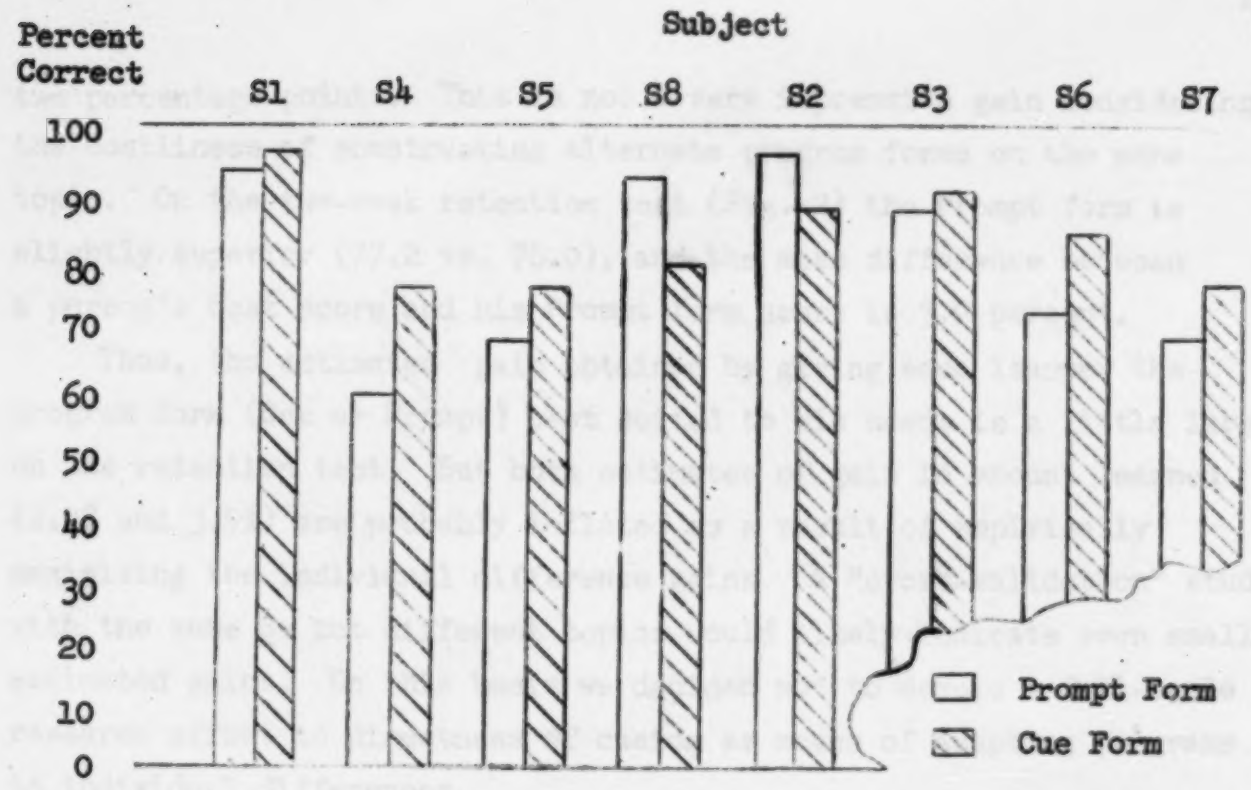

Fig. 1. Percent correct on immediate post-tests, adjusted for topic differences.

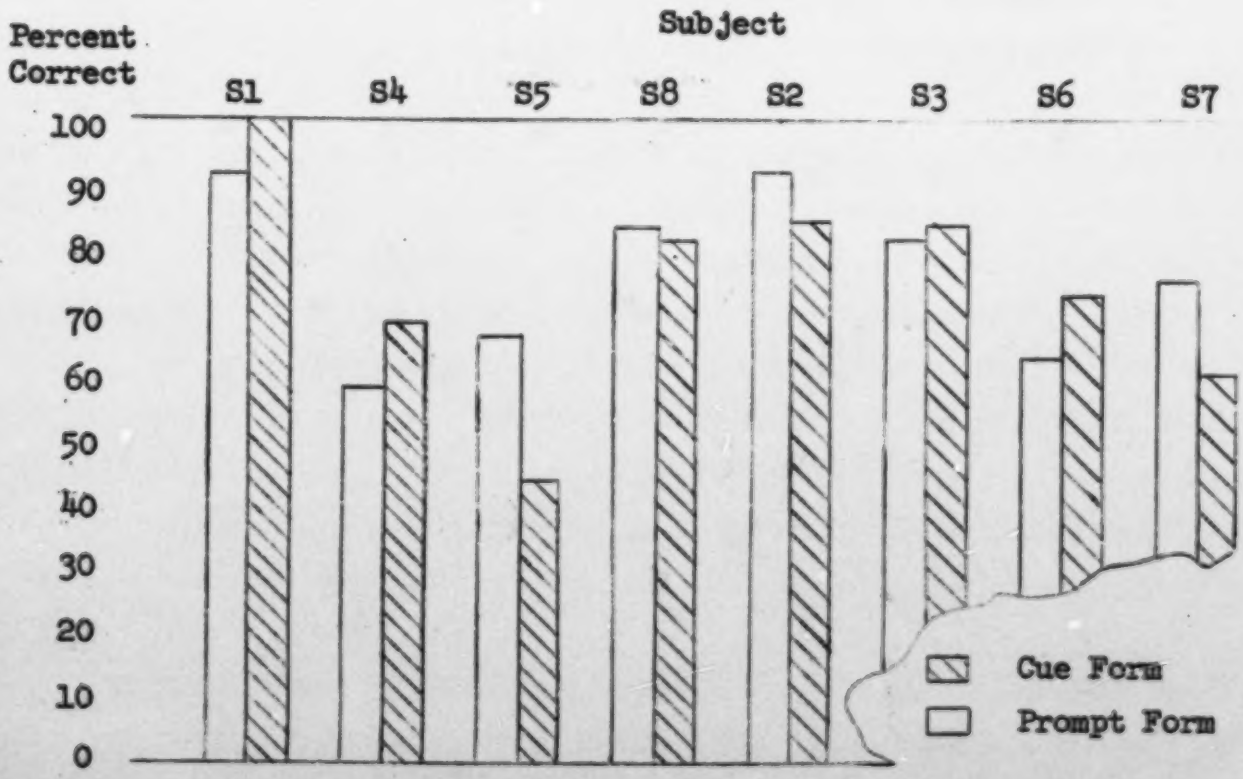

Fig. 2. Percent correct on 2-week retention tests, adjusted for topic differences.

two percentage points. This is not a very impressive gain considering the costliness of constructing alternate program forms on the same topic. On the two-week retention test (Fig. 2) the Prompt form is slightly superior (77.2 vs. 76.0), and the mean difference between a person's best score and his Prompt form score is 3.9 percent.

Thus, the estimated gain obtained by giving each learner the program form (Cue or Prompt) best suited to his needs is a little larger on the retention test. But both estimates of gain in amount learned (2.0% and 3.9%) are probably inflated as a result of empirically maximizing the individual difference gains. A "cross-validation" study with the same Ss but different topics would likely indicate even smaller estimated gains. On this basis we decided not to devote a full-scale research effort to directness of cueing as means of adapting programs to individual differences.

Optional Response

The second pilot study also originated within the cue-response-feedback conceptual framework. Its focus was a variable which is central to both learning theory and educational research: the role of overt response, or active participation, in learning. One could directly ask whether some persons learn better by active responding and others by covert or passive techniques, but it seemed more promising to consider specific ways in which overt activity might relate to effective learning.

If writing out an answer makes it "learned better" in some way than merely reading or thinking it, then writing out wrong answers should be detrimental to the learning desired, as stated by Skinner (11). Many programers have minimized errors by making all program responses very easy, perhaps at the cost of boring or insulting some learners.

Another way to minimize wrong overt responses is to instruct the learner to write in words only when he feels sure he is right. We have termed this an "option" instruction. Differences in learning ability, general or specific, should imply variation between persons in the number and type of responses in the learning program which can be given correctly. By the same token, individual differences in prior knowledge should also imply variation in what answers (and how many) are known. An "option" instruction should thus minimize wrong responses for each person according to his ability and specific knowledge while still allowing program frames sufficiently challenging to require effortful thought by most students. If avoiding incorrect overt responses is important to learning, then a group given "option" instructions might be expected to learn better than a group required to write in all the blanks. This was our hypothesis.

Method

The small-step, constructed response program on optics used in the previous pilot study was further refined into one 32-frame, 55-response version representing what seemed to be an optimal level of cueing

directness and response difficulty.

Initial exploration of the technique of optional responding was conducted with the help of several 10th-grade paid volunteers who served individually as tryout Ss. Their performance guided final refinement of the Optics program, the "option" instructions, and the criterion test, in preparation for group administration. The final program was mimeographed and stapled into booklets, one frame per page. Feedback words for each frame were near the right-hand margin and were covered by an opaque slip of paper which S lifted when he had finished responding into the frame.

A total of 62 students in two 8th-grade science classes served as Ss. Both classes were of above-average scholastic ability as determined by school placement tests. The experiment was conducted concurrently in two classrooms, students in each class being assigned randomly to the following four learning conditions*:

(1) Option (n=16). Ss were given the Optics program described above with the following instructions:

> While reading each paragraph and trying to learn what it says, you will notice one or more blank spaces where words have been left out. If you know what word belongs in a given blank, write it in. If you don't know, leave it empty and go on. It is up to you to decide, for each blank separately, whether or not to write in a word (or words). But write in only when you are sure you have the correct words. If you are in doubt, leave the space blank.
>
> After you have completed the paragraph in this manner, writing only in those blanks you are sure of, lift the gray slip on the right to find out what words belonged in the blank spaces. Do not uncover the words until you have finished the whole paragraph and are ready to go on to the next page. Do not change anything you have written or add anything to the blank spaces after you have lifted the gray slip.

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* Investigation of the three control groups (Write-in, Covert, and Reading) was entirely supported by another project with which we coordinated in data-collection. This companion project was a study of response modes in automated instruction, sponsored by the Office of Naval Research (Contract No. NONR-3077 (00)). For a detailed discussion of comparisons among the control groups, see (5).

(2) Write-in (n=16). Ss were given the Optics program with normal instructions requiring them to write an answer in every blank.

(3) Covert (n=15). These Ss were given the Optics program but wrote in none of the blanks; they were instructed only to try to think of the answers before looking at the feedback words.

(4) Reading (n=15). These Ss received the same set of frames except that no words were omitted, so there were neither blanks nor feedback words; the words omitted for the other three groups were included in the text and underlined for the Reading group.

All Ss in a class read the instructions in the front of their booklets while an experimenter read them aloud. The four kinds of learning booklets were color-coded for easy discrimination, and the instructions made it clear which learning procedure any given S was to follow. We informed the Ss that we would evaluate their performance mainly by their scores on the test which was to follow immediately after the "lesson" (program), but that their learning time also would be recorded. Then each S read silently a summary of instructions for his own learning procedure.

Next, all Ss took a short practice program and quiz on mountaineering, to acquaint them with their learning procedures. Every S worked at his own rate through the practice program and test, then the Optics program and the Optics test, in that order.

Results

In order to partial out any group or individual test score differences accounted for by fortuitous differences in ability, especially reading ability, we obtained from school records recent scores of all Ss on the reading portion of the School and College Ability Test (SCAT) (9). This verbal subscore of SCAT served as the control variable in an analysis of covariance of Optics test scores (the correlation between the two measures was .54).

Overall differences in the adjusted mean test scores of the four groups were small, only approaching significance at the .10 level. When the groups were given the same criterion test 10 weeks later,

the same pattern of differences emerged (all means were significantly lower), and this time differences surpassed the .05 level of significance. The adjusted means of the four groups, on both immediate and retention testing, are shown in Figure 3.

The comparison of special interest to our project was that between the Option group and the Write-in group. The test score difference between these two groups was negligible (and contrary to the hypothesis). Nor did the "option" instructions save much time, apparently, as indicated in Table 1, which shows the mean time required to complete the program for each group.

Table 1. Mean time to complete the learning program (and standard deviations)

	Time Spent on Program	
Group	Mean	S.D.
Option	19.81	3.02
Write-in	20.75	4.30
Covert	13.87	3.81
Reading	11.53	3.11

Not counting omitted responses (12% of the blanks), the Option group did make fewer errors on the learning program than the Write-in group (10% vs. 16% errors, $t = 1.9$, $P_{1\text{-tail}} < .05$), as hypothesized. The fact that the Option group did not learn more efficiently in spite of this suggests that adjusting to individual differences in knowledge and ability for the purpose of avoiding a few incorrect responses, is not worthwhile. This does not mean that individual differences in ability or knowledge cannot be utilized to improve learning in other ways. These results do suggest, however, that frequent overt response and avoidance of wrong responses may both be receiving excessive attention in many current programing efforts.

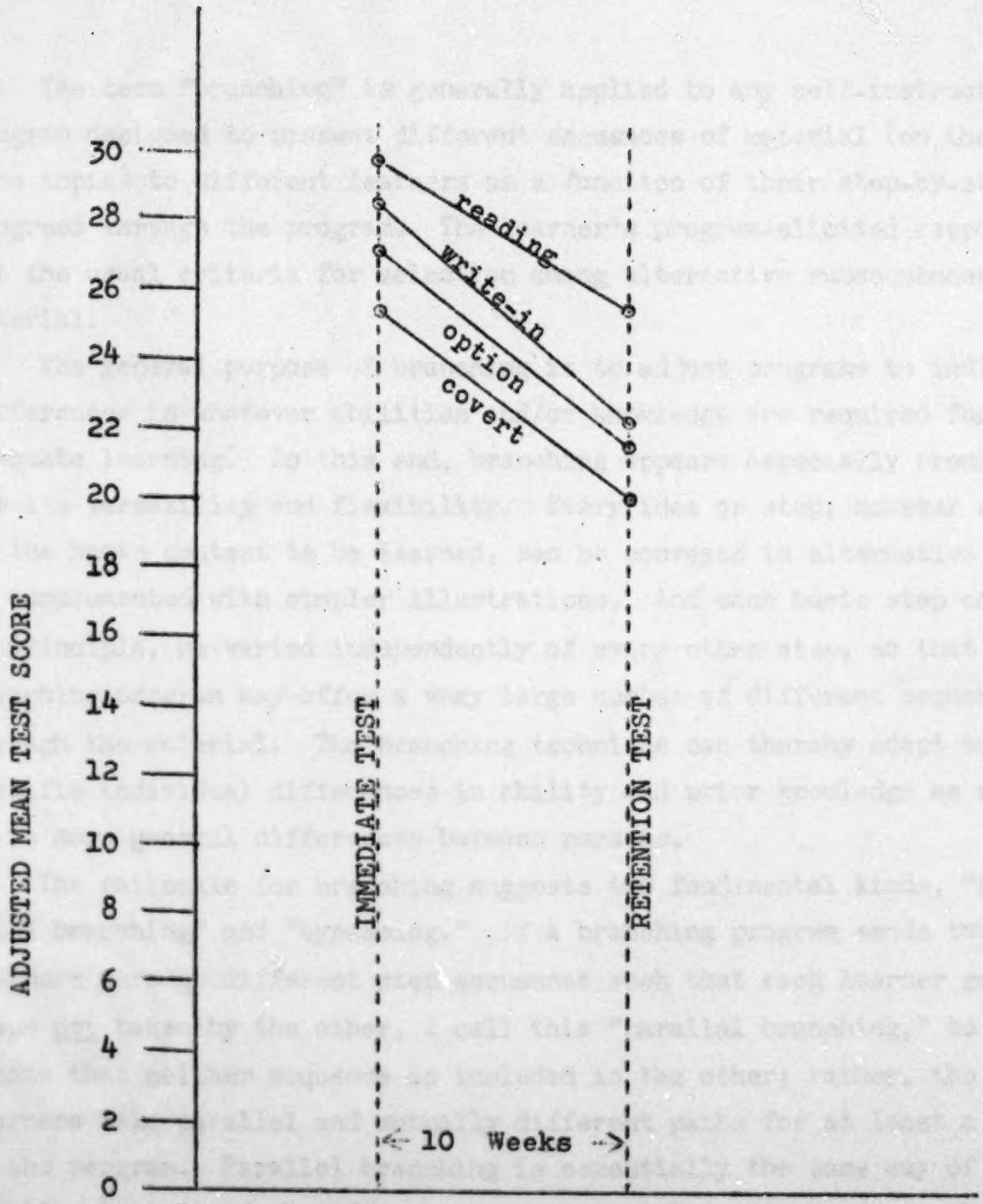

Fig. 3. Mean scores (adjusted by SCAT) of four learning groups on immediate test and 10-week retention test.

Bypassing

The term "branching" is generally applied to any self-instruction program designed to present different sequences of material (on the same topic) to different learners as a function of their step-by-step progress through the program. The learner's program-elicited responses are the usual criteria for selection among alternative subsequences of material.

The general purpose of branching is to adjust programs to individual differences in whatever abilities and/or knowledge are required for adequate learning. To this end, branching appears especially promising for its versatility and flexibility. Every idea or step, however small, in the basic content to be learned, can be conveyed in alternative ways or supplemented with simpler illustrations. And each basic step can, in principle, be varied independently of every other step, so that a branching program may offer a very large number of different sequences through the material. The branching technique can thereby adapt to quite specific individual differences in ability and prior knowledge as well as to more general differences between persons.

The rationale for branching suggests two fundamental kinds, "parallel branching" and "bypassing." If a branching program sends two learners through different step sequences such that each learner gets steps <u>not</u> taken by the other, I call this "parallel branching," to denote that neither sequence is included in the other; rather, the learners take parallel and mutually different paths for at least a part of the program. Parallel branching is essentially the same way of adapting to individual differences as having alternate programs, but applied to shorter sequences of material. "Bypassing," on the other hand, is a term used to refer to programs which have one basic shortest sequence of steps taken by all learners. Branching here consists of taking extra "loops" of material at points in the basic sequence where crucial errors are made or where the learner just bogs down. But the

erring learner returns and resumes the basic sequence without missing a step of it. The learner who masters every basic step without trouble thus "bypasses" the loops of auxiliary material. Other terms synonymous to "bypassing" are "skipping" and "forward branching."

Although bypassing and parallel branching may often be indistinguishable in mechanical format, the underlying hypotheses contrast sharply. Bypassing assumes that there is one basic sequence of steps which is best for nearly everyone in the target population of learners. This one concise sequence, maximizing efficient learning for those who learn most easily, may be too difficult in parts for others to learn efficiently. And since different learners get stuck at different points in the program, the bypassing feature should be more efficient overall than repeated review of one linear sequence which is the same for everyone.

Parallel branching assumes that there are two or more types of learners in the target population, the types being sufficiently different in profile of relative abilities that one type learns a given topic better by method A than by method B while another type learns better by method B than by method A (as discussed on page 3 of this paper). In other words, if parallel branching is to be worthwhile there must be sizable reversals between persons in the relative effectiveness of separate parallel sequences covering the same material. Otherwise it would be more practical to give all learners the one sequence most effective on the average.

Parallel branching, though theoretically promising, is probably a risky investment until we get evidence of substantial individual differences in learning abilities which are closely related to programing characteristics. On the other hand, individual differences in ability to comprehend new material easily are recognized by nearly everyone. Allowing certain learners to bypass unnecessarily redundant (for them) subsequences in the program must certainly save time and can often be engineered very inexpensively.

Logically, one can increase learning efficiency either by saving

time or by raising the level of mastery, but past educational research in general indicates that saving time is much easier to accomplish. Bypassing is patently designed to be a time-saver; whereas parallel branching, though it might save a little time, emphasizes level of mastery, in principle. For these reasons we chose to evaluate bypassing as a means of adapting to individual differences among learners.

Coulson and Silberman (2) pioneered research on this problem with a program on elementary psychology presented to junior college students through a simulated teaching machine. The Ss who followed the bypass procedure (skipping items in the absence of errors) did as well on a criterion test as Ss who followed a fixed-sequence, and learned in 80% as much time. In a later study (10) using a logic program and a computer-based teaching machine with high school students, they hypothesized a higher level of mastery for branching than non-branching Ss. Each branching S was matched by a non-branching S who took the exact same sequence of steps (items) regardless of his own errors. But the branching Ss did no better on the criterion test, nor did they take less time on the program. The authors reasonably suggest that the auxiliary loops of items did not help those who needed them.

Several existing self-instruction programs (8) have been patterned after Crowder's branching technique (3) called "intrinsic programing," but no systematic research evaluating their worth has been reported, to my knowledge. Intrinsic programing represents an interesting combination of bypassing and parallel branching. There is one basic sequence of material to be learned, with bypassable loops which S enters only when he chooses wrong answers. In this sense it is bypassing. Yet there are parallel loops for different errors on the same step. The philosophy seems to be that there is one best errorless path to learning but many ways to go astray on a given point, each calling for a different remedy. Is intrinsic programing superior to simple bypassing on a right-wrong basis? The answer will depend on the extent to which different errors do in fact require different remedial learning loops, and on the programers' ability to discriminate

such important differences among errors in constructing alternative answers and their corresponding loops. Our research has focused on the simpler bypassing procedure of providing only one kind of remedy whatever the nature of the error.

Experimental Program

The advantage already noted of bypassing over repetitions of a linear program is that of letting each learner spend relatively more time on his own weakest points in the program. Another advantage applies especially to highly structured subject matters in which mastery of each step depends on having learned the previous material; that is, bypassing gives help at the time it is most valuable in terms of the sequential dependence of the learning steps. In view of this, we selected a highly structured topic (set theory) which might highlight the merits of bypassing, and constructed a program specifically designed to evaluate bypassing.

Either the fast learner or the slow learner can serve as the starting point for constructing a bypass program. That is, the shortest basic sequence can be constructed first and remedial loops added where necessary. Or one can begin with a full-length sequence intended for the poorest learner, designate bypassable steps, and revise to give the fast learner continuity. Equalitarian instincts led us to employ a compromise. We first listed in order the fundamental ideas to be conveyed, then programed each idea, keeping in mind both the minimum and the maximum-length sequences. Each $8\frac{1}{2}$" x 11" page was treated as a unit of material. The minimum step required of all learners was put at the top and the remainder of the page consisted of auxiliary material on the same subtopic. The number of learner responses elicited per page varied from none to five, the mean number being two. S got feedback by looking on the back of the page (at the same level as his response) where the correct answer was printed or drawn.

Beginning each step in the basic sequence at the top of a new page expedited the bypassing procedure. Under bypassing instructions,

an S skipped directly to the top of the next page whenever the feedback indicated that his answer was correct. Appendix C contains the complete instructions for both linear and bypassing procedures, and sample pages of the full-length program.

The complete program took up 39 pages, some scantly filled, of double-space typing frequently accompanied by diagrams. It covered the fundamental concepts of set theory and presented information to the learner rather densely, and in large steps, for a self-instruction program.

In our previous research with small-step, continuous discourse, constructed response programs, a few Ss complained that the fragmentation of the material into small physically separated steps, and the frequent writing, disrupted continuity of thought (those weren't their exact words). We sought to reduce this effect in our "Sets" program with whole-page units and rarer overt responses. (The findings of the optional response study support reduction of response frequency). To the extent that disruption results from frequent page flipping, our bypassing format should allow greater continuity of thought, especially for those who must need it most, the slow learners who make frequent errors. That is, the erring S who takes all auxiliary loops flips no more pages than the fastest learner.

Closely related to continuity of thought is the process of integrating the specific points learned in previous steps of a program, where the topic is highly structured. We felt that the learners might profit from having ready access, at will, to previously covered parts of the program (one of the advantages of conventional reading matter). Having pages in natural order rather than scrambled, as in most branching programs, made this more feasible for the learner.

Before early tryouts of the program we were somewhat concerned that most pages had more than one feedback answer on the back, and that Ss might "cheat," or at least be disconcerted by the presence of other answers. But there was no such problem as far as we could tell by

casual observation and direct questioning. This arrangement may even have helped to induce in the Ss a "learning set" instead of a "testing set."

After final program revisions based on the learning records of practice Ss, we assembled the instructions and programs in booklet form for group administration.

School A Experiment

Subjects. The first bypassing experiment was conducted in an 8th-grade English class (n=31) at School A in Santa Barbara. The class was designated "upper level" by school placement procedures, and the students' scores on the SCAT test confirmed this.

Method. The "Sets" program was prepared in three forms representing three different learning conditions as follows:

(1) "Bypass" (n=11): These Ss received the full-length program with bypassing instructions (Appendix C).

(2) "Long" (n=10): These Ss received the full-length program with instructions (Appendix C) to proceed linearly through the lesson, skipping nothing.

(3) "Short" (n=10): These Ss had the same linear instructions as the "Long" group, but all auxiliary steps had been removed from the bottom of each page. Only the material leading up to and including the first response appeared on the page.

Having both "Long" and "Short" comparison groups provided a means of assessing the effectiveness of the auxiliary loops of material, which constituted about one-half of the full-length program. The two comparison groups also provided a more informative base line for evaluating the time-efficiency of learning under bypass instructions. A "Bypass" S who made no correct responses would receive the same sequence as a "Long" S. A "Bypass" S whose every response was correct, and who therefore bypassed all loops, would receive the same sequence as an S in the "Short" group.

Student were assigned randomly to learning conditions, and all Ss began the lesson simultaneously. We announced at the start that a test over the lesson would follow immediately afterward. As each S finished his program he was given the 50-item criterion test shown in Appendix D. Both learning times and testing times were recorded for each S. All Ss finished easily in the 95 minutes available for the experiment. (Early in the period one S decided not to finish his test, so his data were omitted from the analyses.)

Results. From the completed programs of the Bypass group, a step-by-step record of program errors and bypassing was made for each S. Inspection of these records confirmed that the bypassing procedure was followed appropriately with rare exceptions (about 10 detectable procedural mistakes in a total of 407 branching-point responses). The mean proportion of pages on which an S bypassed was 79%. Although some pages elicited more errors overall than others, it was a credit to the bypassing technique that Ss differed substantially on which particular pages gave them trouble. In addition, there were wide individual differences in overall amount of bypassing (range: 65% to 92%).

The results of main interest were criterion test scores and learning times. Total score on the School and College Ability Test (SCAT) correlated highly (ave. $r = .79$) with criterion test score and was used as the control variable in an analysis of covariance. The learning group means differed significantly ($F = 3.9$, $P < .05$), the Short group apparently learning less than the Bypass and Long groups. Means and standard deviations on both test score and learning time are shown in Table 2.

Table 2. School A means and standard deviations on criterion test score and learning time

	Raw Test Score		Test Scores Adjusted by SCAT		Learning Time(min.)	
Group	Mean	S.D.	Mean	S.D.(est.)	Mean	S.D.
Bypass	38.5	5.9	37.6	4.9	42.5	8.6
Long	35.0	7.1	37.5	4.9	57.8	6.9
Short	33.7	8.8	32.2	4.9	34.9	10.5

Learning time correlated negligibly with both SCAT and the criterion test, but group differences in learning time were substantial, analysis of variance yielding an F of 17.83 ($P < .001$). Relative time-efficiency of learning is probably best evaluated by reference to Figure 4, which shows each group mean on the two dimensions, amount learned and time spent learning.

Since the Bypass and Long groups learned more than the Short group, the remedial learning loops must have been beneficial. The Bypass Ss took only a fraction of the auxiliary material taken by the Long Ss, yet did as well on the post-test. This suggests that the importance of the loops lies in their accessibility for aid in trouble spots rather than in their general review function. Since taking the auxiliary loops only when needed saved considerable time for Bypass Ss (vs. Long Ss), the bypassing procedure seems to have been valuable, according to these data.

Although these results provided a clear estimate of the time that might be saved by bypassing, we wondered what level of mastery would have been achieved by Ss having a linear program of middle length such that their average learning time was equivalent to the Bypass Ss. In other words, how much more is learned in a given time period with the bypassing procedure than with a linear program? This can be roughly estimated from Figure 4 by imagining the shape of the curve representing "amount learned" as a function of "length

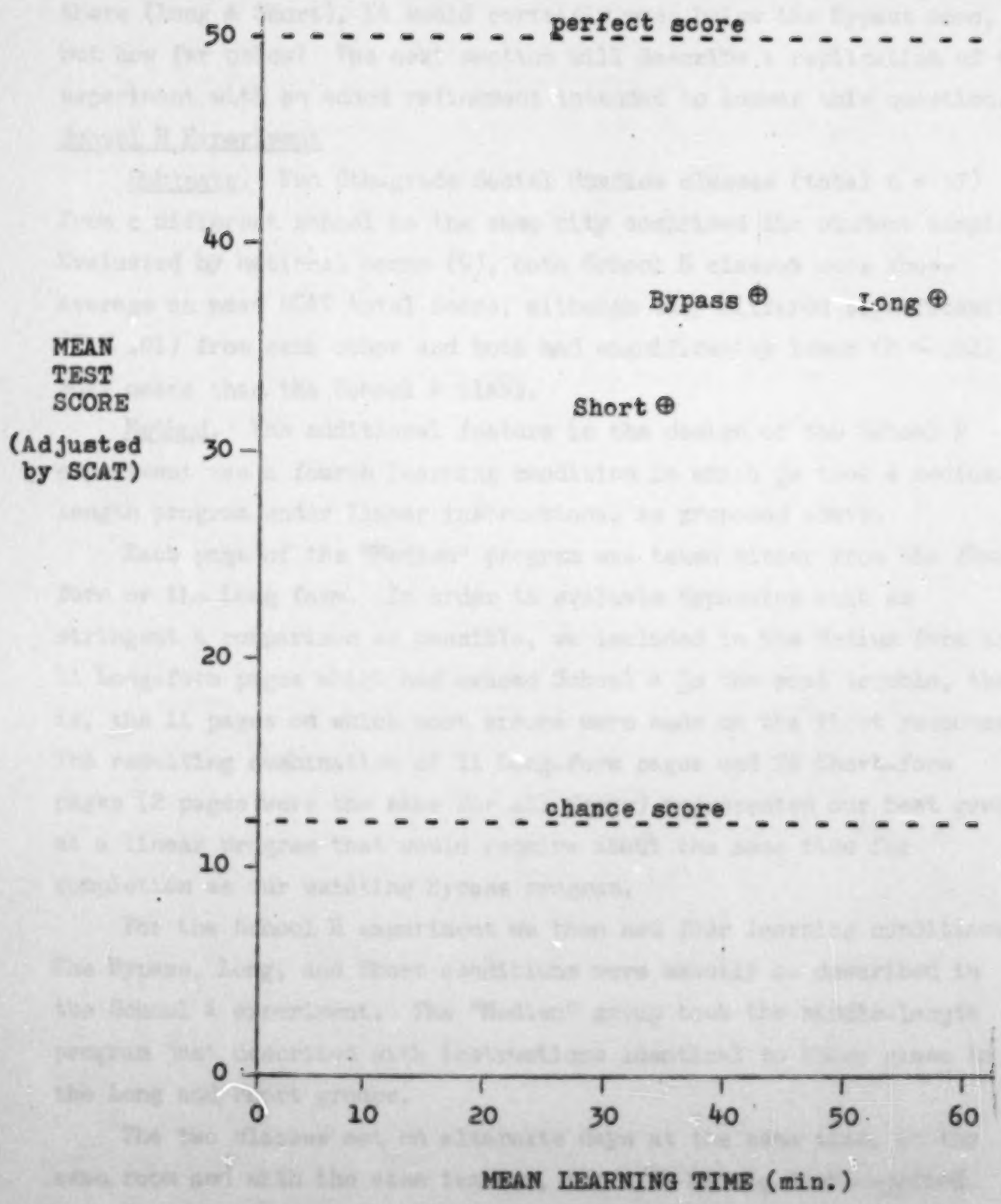

Fig. 4. Amount learned as a function of time spent on the learning program.

of linear program." If the function passed through the two points shown there (Long & Short), it would certainly pass below the Bypass mean, but how far below? The next section will describe a replication of the experiment with an added refinement intended to answer this question.

School B Experiment

Subjects. Two 8th-grade Social Studies classes (total n = 57) from a different school in the same city comprised the student sample. Evaluated by national norms (9), both School B classes were above average on mean SCAT total score, although they differed significantly ($P < .01$) from each other and both had significantly lower ($P < .01$) SCAT means than the School A class.

Method. The additional feature in the design of the School B experiment was a fourth learning condition in which Ss took a medium-length program under linear instructions, as proposed above.

Each page of the "Medium" program was taken either from the Short form or the Long form. In order to evaluate bypassing with as stringent a comparison as possible, we included in the Medium form the 11 Long-form pages which had caused School A Ss the most trouble, that is, the 11 pages on which most errors were made on the first response. The resulting combination of 11 Long-form pages and 26 Short-form pages (2 pages were the same for all forms) represented our best guess at a linear program that would require about the same time for completion as our existing Bypass program.

For the School B experiment we then had four learning conditions. The Bypass, Long, and Short conditions were exactly as described in the School A experiment. The "Medium" group took the middle-length program just described with instructions identical to those given to the Long and Short groups.

The two classes met on alternate days at the same time, in the same room and with the same teacher, for a 95 minute double-period. The administrative procedure followed in each class was that described for School A, students being assigned randomly to learning conditions and each S taking a criterion test (Appendix D) immediately after

finishing his program. Several Ss (perhaps 20%) were working too slowly to finish on time at their natural rate and so were reminded of the limited time available. Many of these were not quite finished with test when the period ended. This procedural flaw was a surprise in light of our experience at School A, where all finished easily and where learning time correlated zero with SCAT scores. (For this reason we were relatively unconcerned about SCAT score differences at the time of data-collection.)

Fortunately we had scheduled the following class meeting (two days later) for both classes in order to administer a questionnaire and a parallel form of the criterion test. The students had not been told in advance of the second experimental meeting. During the first 10 minutes of class the few Ss who had not finished before were given their tests to complete while all other students filled out a questionnaire. Then all Ss were given the parallel form of the criterion test and allowed all the time they wanted to complete it. We felt that if the deviant time schedule on which those few Ss took the first criterion test involved extraneous effects on the experimental group means, such effects would become apparent on comparison of the two sets of results from the parallel criterion tests.

One S in the Long group failed to finished the learning program; one S in the Bypass group ignored the bypassing instructions. Data from these two Ss were omitted from the analyses.

Results. At school B, as at School A, there was appreciable variation among Bypass Ss on which auxiliary steps were bypassed, and on total number of bypasses.

Learning time differences among the experimental groups of School B were in the same pattern as at School A and were statistically significant ($P < .001$), though all groups took longer than their corresponding groups in School A. Also, absolute time differences were smaller, probably because the slower Ss were induced to hurry at School B. Learning time again correlated (within-groups) negligibly with SCAT and with both criterion tests.

But the similarity between schools ended when it came to test scores. Table 3 shows means and standard deviations for each learning condition on the two criterion tests and on learning time. The within-groups correlation between SCAT-Total score and criterion test score was substantially lower than at School A; .31 for the first criterion test and .50 for the second. Analyses of covariance of scores on both criterion tests, with SCAT-Total as the control variable, yielded negligible differences among learning groups ($F = 1.48, 1.46$). The groups having longer programs fared slightly better, compared to the Short group, on the second criterion test than on the first, but on both tests overall differences among group means were too small to discuss.

Two Experiments in Retrospect

Instead of giving a quantitative answer to the question "How much more can be learned per time period by bypassing?" the School B results reopened the issue of whether bypassing has any merit at all. When the data from the two schools were pooled, the criterion test score differences between groups were nil. However, comparison of the two schools in regard to group differences on the first criterion test (omitting the Medium group) yielded a significant school-by-learning method interaction ($F = 3.3$, $P < .05$), so perhaps it is more appropriate to interpret the two experiments jointly but separately.

The main discrepancy between schools indicated by this interaction lies in the amount learned by the Short group in comparison to the other groups. In the School B replication the Short learning condition maintained almost the same mean test score as at School A (in spite of SCAT score differences) while the Long and Bypass conditions dropped 6 to 8 points on the test, or about $1\ 1/2\ \sigma$. Time pressure during testing at School B is a weak explanation of this interaction because the results were very similar on the second criterion test given under no time pressure. There is another seemingly sensible explanation which is somewhat speculative, but which is supported by a fair amount of circumstantial evidence. The line of reasoning is as follows:

TABLE 3. School B means and standard deviations on two criterion tests and learning time.

First Criterion Test

Group	Raw Scores		Scores Adjusted by SCAT	
	Mean	S.D.	Mean	S.D.(est.)
Short	32.6	5.2	32.1	5.7
Medium	27.4	7.0	27.8	5.7
Bypass	29.9	4.9	29.8	5.7
Long	31.0	6.4	31.3	5.7

Second Criterion Test

Group	Raw Scores		Scores Adjusted by SCAT	
	Mean	S.D.	Mean	S.D.(est.)
Short	19.7	2.9	19.1	3.5
Medium	18.7	4.1	19.1	3.5
Bypass	19.2	3.7	19.0	3.5
Long	21.1	4.9	21.4	3.5

Learning Time

Group	Mean	S.D.
Short	42.6	7.4
Medium	48.1	9.2
Bypass	53.1	9.7
Long	60.2	7.2

If motivation for the experimental learning task was substantially lower in general at School B than at School A, then satiation may have had an earlier and stronger effect on performance. That is, a general drop in interest and attention to the task midway through the period would have diminished the amount learned from then on. If such a satiation effect had reached its peak about halfway through the 95-minute period at School B, most of the Short group would have been finished with the program, while most Ss in the Bypass and Long groups would not. The latter may thus have learned very little from material presented late in the period. In other words, while everyone was "fresh" the Short group covered all the concepts to be tested on later and learned them well, but the other groups learned well only the early parts of the program. In School A, by this argument, higher motivation maintained everyone's interest long enough that there was no appreciable differential effect between groups.

There were several indirect indications that general motivation for the learning task was lower at School B:

(1) Social Studies (especially when conducted by a bright and energetic young man, as at School B) is usually considered to be more fun for the students than is English (School A). Even though both teachers gave excellent cooperation, 90 continuous minutes of set theory may have seemed more unpleasant, by contrast, to a Social Studies class than to an English class.

(2) The experimenters noted during data-collection at School B that the students, though docile, seemed less enthusiastic than at School A. A teacher at School B volunteered the same impression independently.

(3) SCAT scores were lower at School B, and despite its manifest purpose, any such test probably reflects motivation in part. Also, in a school which challenges them, students of higher ability are generally believed to have higher motivation to learn.

(4) The cultural and socioeconomic settings of the two schools were different. School A drew more uniformly from upper-middle-class families, who may tend to instill an especially high desire for school achievement in their children.

The above factors are consistent in suggesting general motivational differences between the two samples, but what of the argument that lower motivation implies earlier satiation accompanied by a drop in learning rate? There was one source of evidence of such a differential drop-off between schools. Two set theory concepts, "complement" and "empty set," were introduced late in the program. If the satiation reasoning holds, then Long and Bypass Ss at School B should have had disproportionately low scores on test items requiring knowledge of these concepts. (Items on each set concept were distributed fairly evenly throughout the criterion tests, so that time pressure near the end of the test would not adversely affect concepts encountered late in the program.)

For each S we computed a difference score (test score on concepts learned early in the program minus test score on late concepts) representing the degree of drop-off in amount learned in the last part of the program. These drop-off scores were the entries in a two-factor analysis of variance. The two factors were school and learning group. (The Bypass and Long groups were combined; the Medium group of School B was omitted). The resulting 2 x 2 design permitted a one-tailed test of the school-by-group interaction, the hypothesis being that the Bypass-plus-Long group at School B would have higher drop-off scores as a result of satiation. This effect was present and significant in the predicted direction ($F = 3.5$, $P_{1\text{-tail}} < .05$). Thus, there is empirical support for the hypothesis that the difference between schools in experimental results is attributable to differential levels of motivation and satiation.

It appears that no simple conclusion about the general effectiveness of bypassing is justified at present. Perhaps the most important implication of the two experiments is that the effect of bypassing on

time-efficiency of learning may vary appreciably from one student population to another. A replication of the School B experiment in another city is underway at present, and will, we hope, shed more light on the value of bypassing.

Traditional Ability Variables

The first variable usually called to mind by the mention of individual differences in ability is general ability, or intelligence. Perhaps a more fitting label for the actual measures in use would be "general school ability." The SCAT test is one such measure on which our research to date provides evidence for testing ad hoc hypotheses about how individual differences in ability interact with program differences in affecting learning.

It is conceivable that the effectiveness of bypassing is related to general ability as measured by the SCAT-Total score. If so, the correlation between SCAT and criterion test score should have varied appreciably between groups in the bypassing experiments. For both schools this hypothesis was checked out by an F-test of homogeneity of regression (of test score on SCAT) (6). The differences between groups were negligible, both sets of data yielding F-values less than one. Thus, there was no indication that linear and bypassing programs are differentially effective at different levels of general ability, as measured by SCAT.

The optional response study provided data for testing the hypothesis that the programing methods employed there (optional response, normal write-in, covert response, and reading) were differentially effective for students having different degrees of verbal ability. An F-test of homogeneity of regression among experimental groups yielded a marginal value ($F = 1.75$, $.10 < P < .20$), suggesting a slight tendency for different response modes to be optimal for different ability levels. But the criterion means did not appear to differ in a meaningful order of progression, so this result may not deserve notice.

We also examined the proposition that a learner's profile of more specific abilities might interact with programing methods in determining the effectiveness of learning. The two principal ability factors commonly derived from factor analyses of scholastic

ability tests have been a verbal or linguistic factor and a quantitative or abstract reasoning factor. If individual differences in ability profile interact with programing variables, these two factors would seem to be the most promising traditional variables on which to contrast profiles. For the Ss in the School A experiment on bypassing, we had available both the Verbal and Quantitative subscores on the SCAT test. Verbal (V) and Quantitative (Q) scores correlated only .19 in the School A sample, suggesting that profile differences might be large enough to be of importance. However this correlation was artificially low because of the homogeneity of the sample on SCAT total score. An unselected 8th-grade sample of 100 scores from the same school yielded a V-Q correlation of .65, in agreement with national norms. Nevertheless, on the basis of the difference between an S's V and Q scores two groups of 9 Ss each were selected as the most contrasting profiles (high Q, low V vs. high V, low Q) that the sample could provide. These two groups were compared on criterion test scores, learning times and program errors (both total number of errors and page-by-page differences). These analyses yielded no evidence of differences between profile opposites. Small differences may not have been detected, however, since the Ns were small.

Future Project Research

From available indications, bypassing is still one of the more hopeful ways of adjusting self-instruction programs to individual differences among learners. Like others, we have obtained conflicting findings, suggesting the extraneous influence of one or more important variables. In hope of removing some of the ambiguity surrounding bypassing, we intend to continue intensive investigation of the technique. This may involve trying new criteria for branching, such as the learner's satisfaction with his own progress. It may mean an extension of the evaluation of bypassing to non-mathematical subject matters as a way of generalizing results and seeking knowledge of how bypassing relates to nature and organization of material. Or we may concentrate on auxiliary loops as the crucial part of a bypassing program. Perhaps a loop should begin with a small-step search for a meaningful starting point of explanation, then proceed through step-by-step construction of the troublesome idea.

Depending upon the outcome of further research on bypassing, we may initiate pilot studies on either of two other initially proposed sources of individual differences in automated learning. These are (a) step size: some learners may profit from ingesting quite a large amount of material before actively responding to, integrating, or reviewing what has been covered; others may learn optimally from much smaller steps; (b) type of organization of material: for example some may learn better by inductive presentation and others by a more deductive arrangement in which rules always precede their illustrations.

Finally, we shall watch for interactions between programing variables and traditional measures of individual differences, on which the wealth of existing data would make early application of such findings quite practicable.

Summary

Several possible ways of adjusting self-instruction programs to individual differences among learners were explored in experimental pilot studies. The programs utilized a variety of response modes and step sizes, and presented topics within physics and mathematics to students of 8th, 9th, and 10th grade levels.

The first pilot study focused on personal differences in ability to learn from direct prompting, vs. indirect cueing, of overt responses. Each of 8 Ss was given a "Cue" form and a "Prompt" form of programed instruction, one form on optics and the other on static electricity (counterbalanced). Some Ss did better with the Cue form and others with the Prompt form, but such individual differences were too small (2% or 3% on a criterion test) to justify a full-scale follow-up investigation.

A second study examined the technique of asking the learner to write responses in the blanks of program frames only when he felt he knew the correct response. This "optional" responding was intended to utilize individual differences in learning ability and prior knowledge to avoid wrong responses in each frame, on the assumption that errors are detrimental to learning. We gave 16 Ss an optics program with "option" instructions and compared their scores on a post-test with those of a group of Ss who wrote in all program blanks. Optional responding, though it reduced errors slightly, neither raised test scores nor saved learning time. This outcome cast doubt on the evil of overt errors as well as on the value of the optional response instructions.

In two different schools we evaluated the technique of "bypassing," which allows an S to skip auxiliary loops of instruction as long as he is successfully progressing through the basic sequence of material. A large-step, 39-page, programed text on set theo[illegible] was prepared in "Short" and "Long" forms differing in amount of [illegible]liary instruction presented on each page.

Thirty-one Ss at School A were randomly assigned to groups. Two of these groups took the Sets program with "linear" instructions (no bypassing permitted), one group taking the Short form and the other the Long form. A "Bypass" group took the Long form of the program with instructions to bypass to the next page after every correct response. On post-test scores the Bypass and Long groups surpassed the Short group by equal amounts, but the Bypass group completed the program in substantially less time.

The experiment was replicated at School B (n=57), with the addition of a group who took a medium-length form of the program under linear instructions. Learning times were comparable to those at School A, but test score means of the four groups differed neglibibly. The school-by-learning-method interaction in test scores was significant, and an ad hoc explanation of the conflicting results in different schools was advanced.

Scholastic ability, as measured by SCAT (9), served as a control measure in the optional response and bypassing studies. These data were re-analyzed to test for ability-by-learning-method interactions, but there was little or no evidence that the relative effectiveness of the various program forms changes with level of scholastic ability. Students having opposite profiles with respect to verbal vs. quantitative abilities were identified from the School A sample of the bypassing studies. Comparison of these profile opposites on learning performance yielded no significant differences.

Initial ideas for future research were outlined. These center primarily around clarification of important variables in bypassing, which appears to be a potentially versatile technique for adapting programed instruction to individual differences.

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APPENDICES

A: Sample frames of Static Electricty Program

B: Cue-prompt study: raw data and summary analyses of variance

C: Sample pages of "Sets" program with linear and bypassing instructions

D: Criterion test on "Sets" program

Appendix A

Sample sequences of frames from alternate forms of the self-instruction program on static electricity. On the left side of each page is the "Prompt" form employing relatively direct cueing and prompting; on the right is the "Cue" form in which cueing is more indirect.

STATIC ELECTRICITY A

4A

Static electricity can also cause objects to repel each other. When a comb rubbed through fur is brought near another comb rubbed through fur, the combs will not attract each other but will _____ each other.

Answer: repel

5A

Knowing that two rubbed combs will repel each other, you would predict that two amber rods would also _____ each other after they have been rubbed.

Answer: repel

6A

Static electricity causes some objects to come together; that is, to _____ each other. It causes other objects to move apart; that is

Answer: attract

STATIC ELECTRICITY B

4B

Static electricity not only causes objects to attract each other; it also causes objects to _____ each other. When a comb rubbed through fur is brought near another comb which has been rubbed through fur, the combs will not attract each other, but will _____ each other.

Answer: repel

Answer: repel

5B

Knowing what two rubbed combs do to each other, you would predict that two amber rods would also _____ each other after they have been rubbed.

Answer: repel

6B

Static electricity causes some objects to _____ each other. It causes other objects to _____ each other.

Answer: attract

Answer: repel

STATIC ELECTRICITY A

7A

Both attraction and repulsion are examples of _____ _____. Objects moving together is known as _____. Objects moving away from each other is known as _____.

Answer

static electricity
attraction
repulsion

8A

When we rub a piece of amber on a silk cloth, the amber receives a charge of electricity. If we rub a comb through hair, the comb also receives a _____ of electricity. Rubbing a balloon against a wool rug will give the balloon a _____ of electricity.

charge
charge

9A

Static electricity means that an object has a _____ of _____.

charge
electricity

STATIC ELECTRICITY B

7B

We have learned that both _____ and _____ are examples of static electricity.

Answer

attraction

8B

When we rub a piece of amber on a silk cloth, the amber receives a charge of electricity. If we rub a comb through hair or a balloon against a wool rug, the comb and the balloon will each receive a _____ of electricity.

charge

9B

Static electricity means that an object has a _____ of _____.

charge
electricity

Appendix B

Raw percentage scores and summary analyses of variance on immediate and 2-week retention tests, as follows:

Table B1. Unadjusted percent-correct scores on the immediate post-test.

Table B2. Summary analysis of variance of immediate post-test percent score.

Table B3. Unadjusted percent-correct scores on 2-week retention tests.

Table B4. Summary analysis of variance of 2-week retention percent scores.

TABLE B1. Unadjusted percent-correct scores on the immediate post-test.

	Static Electricity		Optics	
SUBJECT	CUE	PROMPT	CUE	PROMPT
S1	-	100	91	-
S4	-	64	70	-
S5	-	73	70	-
S8	-	98	74	-
S2	94	-	-	90
S3	96	-	-	83
S6	90	-	-	65
S7	81	-	-	61

TABLE B2. Summary analysis of variance of immediate post-test percent scores.

Source of Variance		d.f.	SS	MS
Between Ss		7	1,653	236.1
Form x Topic (Interaction)		1	25	25.0
Error		6	1,628	271.3
Within Ss		8	956	119.5
Form		1	64	64.0
Topic		1	529	529.0
S x Form S x Topic	Interaction*	6	363	60.5
TOTAL		15	2,609	173.9

* The S x Form and S x Topic interactions are indistinguishable. Also there is no appropriate F-test for the significance of this interaction.

TABLE B3. Unadjusted percent-correct scores on 2-week retention tests.

	Static Electricity		Optics	
SUBJECT	CUE	PROMPT	CUE	PROMPT
S1	-	100	92	-
S4	-	67	61	-
S5	-	76	36	-
S8	-	93	75	-
S2	94	-	-	84
S3	93	-	-	75
S6	82	-	-	55
S7	69	--	-	68

TABLE B4. Summary analysis of variance of 2-week retention percent scores.

Source of Variance	d.f.	SS	MS
Between Ss	7	2,706	386.6
Form x Topic (Interaction)	1	25	25.0
Error	6	2,681	446.8
Within Ss	8	1,589	198.6
Form	1	16	16.0
Topic	1	1,024	1,024.0
S x Form) S x Topic) Interaction*	6	549	91.5
TOTAL	15	4,295	286.3

* The S x Form and S x Topic interactions are indistinguishable. Also there is no appropriate F-test for the significance of this interaction.

Appendix C

Instructions and sample pages from the self-instruction program, "An Introduction to Sets." The first page of instructions (i) was the same for all experimental groups. The second page (ii) was different for the Bypass learning condition, as shown.

(First page of instructions for all learning conditions)

INSTRUCTIONS

This booklet contains a complete lesson on reasoning about "sets of things." It is designed to enable you to learn rapidly and thoroughly. For this reason, on nearly every page you will take an active part in checking on how well you are learning. That is, you will answer a question about what you have just read, or you will fill in a blank space where a word or symbol is missing, or mark on diagram as instructed. After doing any one of these things, look on the back of that page immediately to see if you responded correctly. The correct answer will appear on the back at the same level as the question or picture you have just completed. Work the examples below to be sure you understand this.

Examples:

Suppose that Martians all have two heads and only one foot. Would ten Martians have the same number of heads as five Earthmen?

Yes _____ (After you have checked yes or no,
No _____ or put a "?" if you don't know, see right answer on back here ---------->)

You come across a roomful of these Martians and decide it's simpler to count feet than heads. There are 12 feet in the room. From this you know that there are ____ Martians in the room. (Always check your answer on back immediately ---------->)

The rectangle at right represents the surface of the planet Mars. The area inside the circle is the part supporting plant life, and the area inside the triangle represents the part supporting animal life. With your pencil, shade in the portion representing that area of Mars on which plants but no animals live. Don't try to be too neat or exact; sketch a few lines.

(Always check your answer on back--)

(Second page of instructions for linear-program learning conditions)

The purpose of these actions required of you is to help you to learn efficiently, so don't dwell for long on one answer. If you can't think of a good guess, write in a question mark (?) before looking on the back for the right answer.

You may turn back to earlier pages any time you want to, but please don't add any new answers. Your mistakes are our only means of improving the lesson. You may write and draw anywhere on booklet if it helps you to study.

Here is a review of important things to remember:

1. Whenever you make a response (such as filling in a word or diagram, or checking "yes" or "no"), be sure to check the correctness of your answer on the back immediately.
2. If you can't think of a good guess, always put a question mark (?) in the blank or diagram before checking to see the right answer.
3. Don't worry about mistakes; they may even help you learn. Remember, this is not a test.
4. Work at your own speed, but learn as much as you can in the time you spend.

STOP HERE. DO NOT TURN THE PAGE UNTIL INSTRUCTED TO DO SO.

(Second page of instructions for Bypass learning condition)

The purpose of these actions required of you is to help you learn efficiently, so don't dwell for long on one answer. If you can't think of a good guess, write in a question mark(?) before looking on the back for the right answer.

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Whenever you make a response (such as filling in a word or diagram, or checking "yes" or "no") be sure to check the correctness of your answer on the back immediately, and IF YOUR ANSWER WAS RIGHT GO DIRECTLY TO THE NEXT PAGE WITHOUT FINISHING THE PAGE YOU WERE ON. If your answer was not right, continue working on the same page.

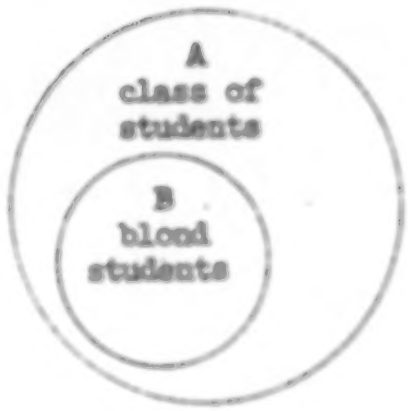
The reason for your doing this is that each page treats only one topic, and we want you to spend the most time on pages that give you the most trouble. So any time you check the back of a page and see that your answer was correct, skip directly to the next page.

Work at your own speed, but learn as much as you can in the time you spend. Always write in a "?" before looking on the back if you can not think of the answer (or a good guess). Don't worry about mistakes; they may even help you learn. Remember, this is not a test.

STOP HERE. DO NOT TURN THE PAGE UNTIL INSTRUCTED TO DO SO.

To illustrate what we are going to say about sets, we will use diagrams. The area inside the circle at the right represents a set. Let us say, for example, that Set A is a class of students.

Within Set A there is a set of blond students, as shown in the 2nd diagram. Let us refer to the blond students in this class as Set B. As you can see, Set B is completely included in Set A. That is, the blond students in the class are part of the whole class. Any time one set is entirely included in another, we say it is a subset of the other. In the diagram, Set B is included in Set A, so Set B is a subset of _____.



Another example of subsets:

Let us call all the houses in Centerville a set. Then all brick houses in Centerville would be a subset of this set. All the wood houses would be another subset. Houses with two bedrooms make up a third subset. Houses on Elm Street are another subset.

Another example of subsets:

The set of all days in the year 1960 has many subsets of days. All the days on which you went to school is one subset. The days on which it rained is another subset; the days you went out of town is another; all Tuesdays in the year is another.

"All days since 1900" - Is this a subset of "days in the year 1960"?

Yes _____

No _____

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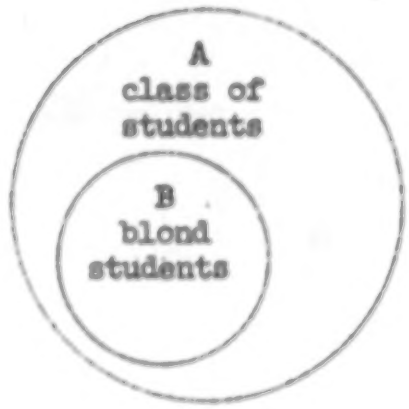

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"All days since 1900" Is this a subset of "days in the year 1960"?

Yes _____

No _____

$\subset$ = included in

The diagram at right shows three sets:

U = all men

A = smiling men

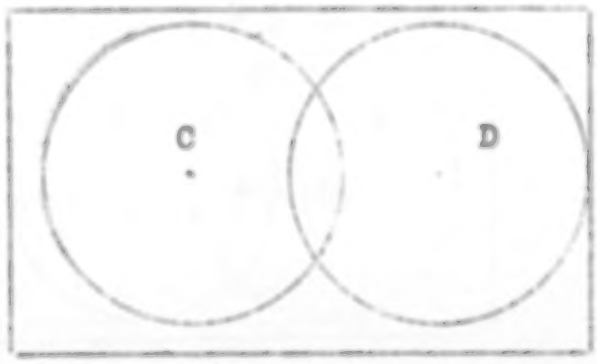
B = bearded men

Each man is an element.

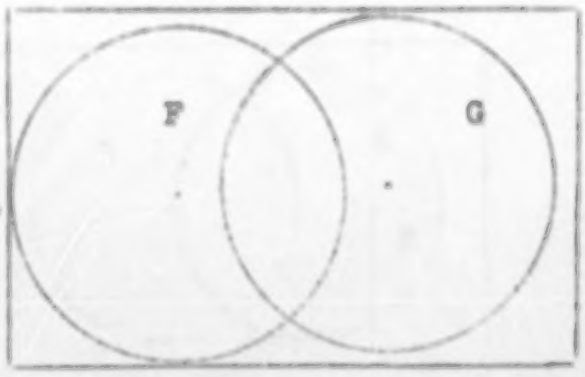
As you can see, some men are both smiling and bearded. These men (elements) who belong to both sets at once make up the intersection of Sets A and B. To be included in the intersection of A and B, a man must be both smiling and bearded.

In other words, whenever two sets overlap, such as A and B in the diagram, the overlapping part is the intersection.

The second diagram shows two overlapping sets, C and D.
Place an X on the diagram to show where we would find an element belonging to the intersection of C and D.



Reread this page carefully if you were mistaken. Then place an N on the third diagram to show where we would find an element that belongs to Set F but is not in the intersection of F and G.



$\subset$ = included in
$\cap$ = intersection
$\cup$ = union
$\sim$ = complement
$\emptyset$ = empty set

Suppose U has three subsets, F, G and H. Sets F and G do not overlap, or in symbols,

$$F \cap G = \emptyset$$

Also, $H \subset G$

From this it follows that $F \cap H =$ ____

Since $H \subset G$, what does the intersection of H and G equal?

$$H \cap G =$$ ____

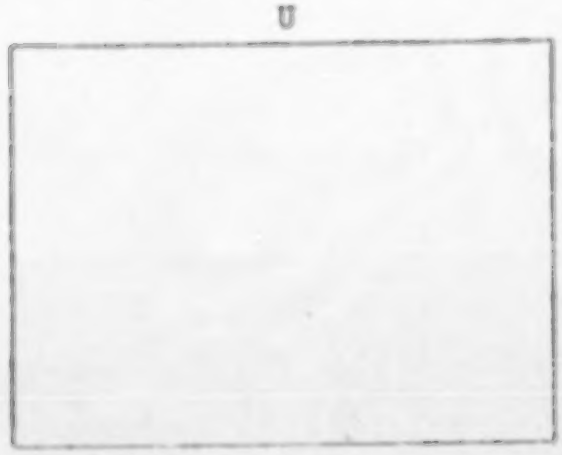
What does the union of H and G equal?

$$H \cup G =$$ ____

Of the three sets F, G and H, which one is included in $\tilde{G}$?

____ $\subset \tilde{G}$

Draw in the diagram showing F, G and H as defined above.



Appendix D

Test on the self-instruction program, "An Introduction to Sets." Analyses reported in the text are based on a scoring key assigning one point to each of the 50 items. The tests from School B were also scored with a second key assigning weights to items according to the number of "set" concepts required to solve the problem. But since the two scorings correlated .99, the latter key was dropped from further analyses.

I. What word was used in the lesson to describe a group of objects that belong together if you have no particular object in mind? _____

Each individual object or "thing" in a set is called _____.

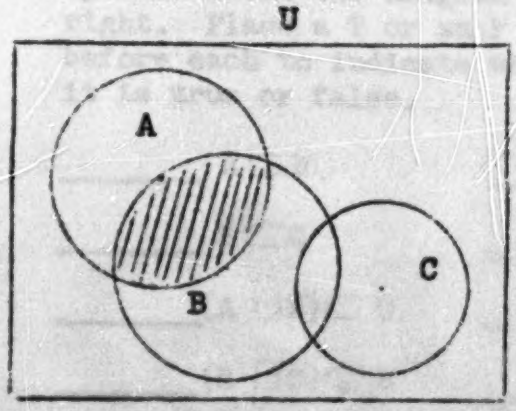
The entire set of things being discussed in a given problem is called the _____ set.

II. Match column A with column B by writing in the number of the correct definition in the blanks provided in column B.

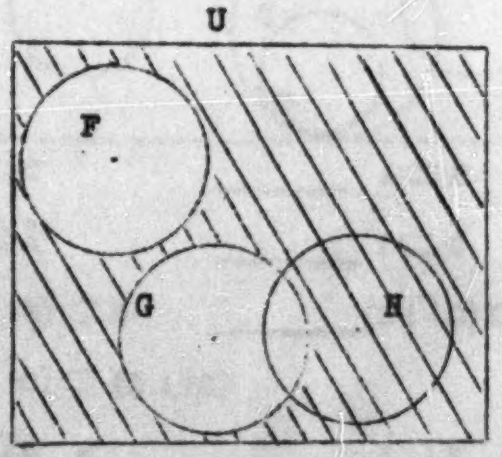
A	B
1. Intersection	_____ $\sim$
2. Union	_____ $\emptyset$
3. Complement	_____ $\cap$
4. Empty set	_____ $\subset$
5. Included in	_____ $\cup$

III. For each diagram on the next page, write in symbols at the left what the shaded area represents. The answers are already given for the first two diagrams below as examples.

$A \cap B$

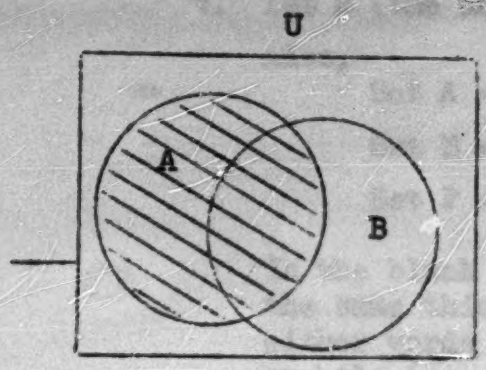


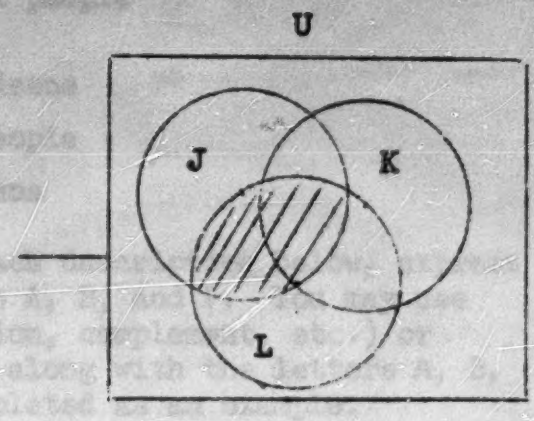
$\widetilde{F \cup G}$

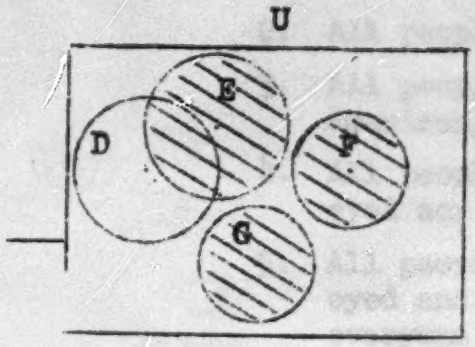


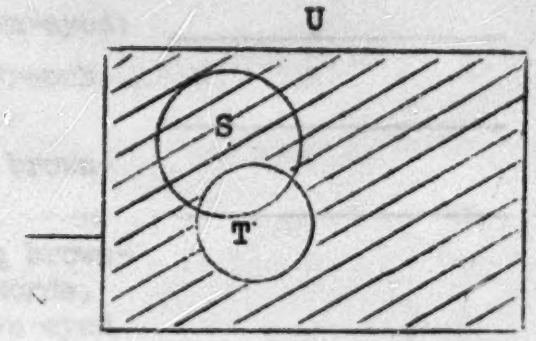
(Use these examples to check your matching for $\cap$ and $\cup$ in II above.)

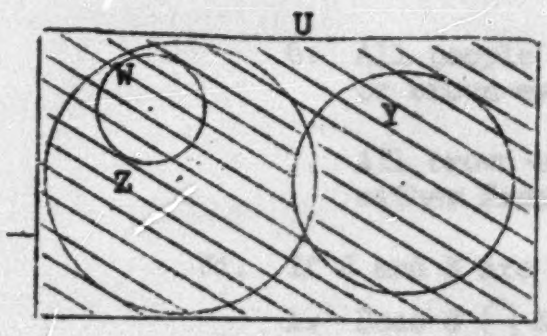
(III. Cont.)

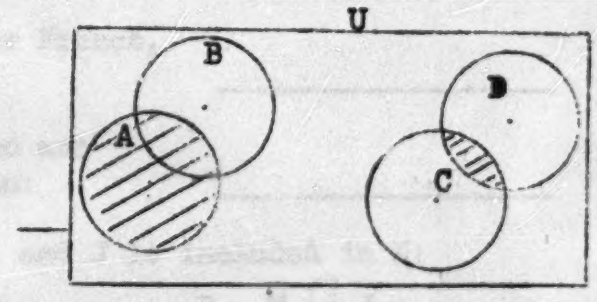




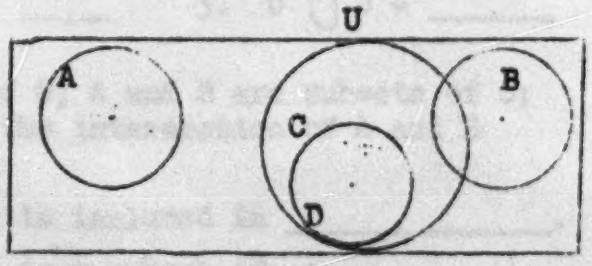








IV. Below are several statements in symbols about the diagram at right. Place a T or an F before each to indicate whether it is true or false.



_____ $A \subset U$ _____ $D \subset C$ _____ $A \subset B$

_____ $B \subset C$ _____ $D \subset \tilde{A}$ _____ $D \subset \tilde{C}$

_____ $(A \cup B) \subset U$ _____ $(A \cup B) \subset D$ _____ $(B \cap C) \subset A$

_____ $(B \cap C) \subset B$ _____ $(B \cap C) \subset (B \cup C)$

_____ $A \subset (\widetilde{B \cup C})$ _____ $A \cap D = \emptyset$ _____ $A \cup B = \emptyset$

_____ $\widetilde{B \cup \tilde{B}} = \emptyset$ _____ $C \cap (A \cup B) = \emptyset$

V. Let U (the universal set) = all people

Also,

Set A = all American citizens

Set B = all brown-eyed people

Set F = all French citizens

In the blank at the right of each description below, express the same thing in terms of Sets A, B, and F. You may use either words (union, intersection, complement, etc.) or symbols ($\sim$, $\cap$, $\cup$, etc.) along with the letters A, B, and F. The first blank is completed as an example.

1. All brown-eyed Americans: $A \cap B$
2. All people who are not brown-eyed: _____
3. All people who are either French, American, or brown-eyed: _____
4. All people who are neither brown-eyed nor French: _____
5. All people who are not <u>both</u> brown-eyed and French (in other words, everyone who is not a "brown-eyed French citizen"): _____
6. All people who are either French, or brown-eyed Americans: _____
7. All brown-eyed people who are either French or American: _____

Vi. If J and K are subsets of U, <u>and J is included in K</u>:

1. Does $J \cap K = \emptyset$? Yes _____ No _____
2. $U \cap J =$ _____
3. $U \cup J =$ _____

VII. If A, B, and C are subsets of U; A and B are subsets of C; and A and B do not overlap (the intersection of A and B equals $\emptyset$.

1. A is included in C and C is included in _____.
2. $\widetilde{C}$ (the complement of C) is a subset of _____.
3. _____ is included in $\widetilde{A}$.
4. The union of A and B is a subset of _____ and also a subset of _____.

VIII. P, Q, and R, are subsets of U.

R is included in the union of P and Q, or in symbols, $R \subset (P \cup Q)$.

1. Is $R \subset P$? Yes _____ No _____ Can't tell _____

2. Is $R \subset U$? Yes _____ No _____ Can't tell _____

3. Does $P \cap Q = \emptyset$ Yes _____ No _____ Can't tell _____

4. Is $R \subset \widetilde{(P \cup Q)}$? Yes _____ No _____ Can't tell _____

IX. In Lakeview High School language department, some students are taking only Spanish, some are taking only French and some are taking both Spanish and French. Draw a diagram showing this relationship. Label the diagram:

(S = the set of students taking Spanish)

(F = the set of students taking French)

Let Set G = all girls at Lakeview High.

And suppose $G \subset \widetilde{(S \cap F)}$.

Are any girls taking both Spanish and French? Yes _____ No _____ Can't tell _____

Are any girls taking French? Yes _____ No _____ Can't tell _____